CHAPTER 6
COSTS OF THE HDVIP AND PSIP

6.1 OVERVIEW

The preceding chapters present a detailed analysis of the technical feasibility of identifying and repairing excessively smoking heavy duty diesel vehicles (HDDV) through the HDVIP and PSIP. Recommended program cutpoints have been developed and the effectiveness and cost of individual vehicle repairs has been quantified. While the technical integrity of the HDVIP and PSIP has been demonstrated, the overall costs and net benefits associated with putting the programs in place remains to be evaluated. The ratio of overall program cost to program benefit provides a useful measure of program effectiveness and allows the HDVIP and PSIP to be directly compared to alternative emissions control strategies.

This chapter quantifies the overall costs of HDVIP and PSIP implementation and enforcement. HDVIP and PSIP cost effectiveness will be calculated in Chapter 6 on the basis of these cost estimates. Overall costs arise from a variety of program requirements, including:

- Labor costs for program administration and enforcement,
- Capital costs for vehicle inspections,
- Costs for vehicle repair, and
- Indirect costs due vehicle and driver out-of-service time.

Section 6.2 provides a brief overview of the administrative, implementation, and enforcement features of the previous HDVIP program. Features discussed are to be retained in the proposed HDVIP and PSIP and, therefore, are indicative of how the ARB will implement and administer these proposed programs. Section 6.3 presents estimates of HDVIP and PSIP staffing and administrative costs, both for the ARB and affected vehicle fleets. While inspection and administrative costs are dependent on the overall vehicle inspection population, vehicle repair costs are dependent on the number of vehicles which fail HDVIP or PSIP inspections. Therefore, an estimate of HDVIP and PSIP program failure rates is required to develop estimates of total HDVIP- and PSIP-related vehicle repair costs. Section 6.4 presents this required estimate of expected HDVIP and PSIP failure rates and Section 6.5 then presents the resulting estimates of overall program repair costs. Section 6.6 summarizes the component costs developed in Sections 6.1 through 6.5.

6.2 PREVIOUS PROGRAM ADMINISTRATION

In accordance with SB 1997 (Presley, 1988), the ARB implemented a roadside inspection program in 1991 to reduce excessive smoke emissions from heavy duty vehicles operating in California. Under this Heavy Duty Vehicle Inspection Program (HDVIP), ARB staff administered a "snap-idle" test (now known as a "snap-acceleration" test) at California Highway Patrol (CHP) inspection facilities and weigh stations as well as random roadside locations in an effort to identify excessively smoking heavy duty vehicles. In October of 1993, the ARB temporarily suspended enforcement of the HDVIP to focus staff efforts on reformulated fuel issues. A companion Periodic Smoke Inspection Program (PSIP) requiring periodic self-inspections for California-based heavy duty fleet vehicles was scheduled for implementation (beginning in 1995) in accordance with SB 2330 (Killea, 1990).

At approximately the same time the ARB suspended enforcement of the HDVIP program, the State Legislature adopted AB 584 (Cortese, 1993). AB 584 instituted specific requirements that must be satisfied by the HDVIP, most notably the use of the Society of Automotive Engineers (SAE) J1667 snap-acceleration inspection procedure (or an equivalent procedure producing "consistent and repeatable results"). Since the J1667 procedure was still under development in 1993, the ARB elected to postpone resumption of the HDVIP and enforcement of the PSIP until all issues related to AB 584 were resolved. The formal adoption of SAE J1667 in 1996 makes such resolution possible and leads directly to the analysis presented in this TSD.

Even though enforcement of the HDVIP has been suspended for nearly four years, the administrative features implemented during the program's 1991-1993 enforcement period provide the backbone for both the administrative structure and implementation procedures that will be required when enforcement of the HDVIP is resumed. Moreover, although the PSIP will now be enforced for the first time, the administrative aspects of the HDVIP are readily transferable to the PSIP and thus provide a firm basis for assessing administrative requirements under the proposed PSIP.

From an administrative standpoint, the original HDVIP and PSIP inspection procedures (that were based on the SAE J1243 inspection procedure) are equivalent to those of the SAE J1667 inspection procedure proposed for use upon resumption of the programs. While measured smoke values can differ between the J1667 and J1243 inspection procedures (due to the incorporation of Bessel filtering in the J1667 procedure), the basic steps required to conduct an inspection and enforce the programs do not change. The steps involved in conducting an inspection under the HDVIP are as follows:

- A test site is determined,
- A vehicle is selected for inspection,
- The vehicle is secured for safety,
- The snap-acceleration test is administered,
- A pass/fail determination is made,
- If the vehicle fails, a citation is issued,
- Vehicle owner compliance with the citation is tracked, and
- If repairs to clear the citation are not undertaken, additional punitive steps are taken to induce compliance.

Under the PSIP, inspections are performed by the subject fleet and, therefore, ARB administrative steps are limited to:

- An audit of fleet maintenance and inspection records, and
- Confirmatory testing of a sample of fleet vehicles (citations are issued for vehicles failing the confirmatory tests and tracked in the same manner as those issued under the HDVIP).

The ARB assembled nine mobile inspection teams, each comprised of two inspectors to conduct the vehicle testing and citation issuance aspects of the original HDVIP[1]. These 18 field personnel were supported by two field supervisors and a core of central office supervisory and administrative staff. Each of the nine inspection teams conducted vehicle

[1] Throughout the remainder of Chapter 6 and all of Chapters 7 and 8, the terminology "original HDVIP" is used when referring specifically to the program administered from 1991 through 1993. Its use is necessary to distinguish the specific features of that program from those of the proposed HDVIP.

inspections at CHP weigh and truck inspection stations, fleet facilities, and random roadside locations. This same administrative approach, using the same nine team, 18 inspector, mobile field staff, is expected to handle vehicle inspection duties under the proposed HDVIP. Moreover, these same staff will be charged with performing PSIP fleet audits as well.

A typical inspection under the original HDVIP would entail a CHP officer directing a randomly selected vehicle to the ARB test area. ARB staff would then provide the driver with general information on the HDVIP and detailed instructions on performing the test procedure. Operation of the vehicle during the test was the responsibility of the vehicle operator, not ARB staff. To ensure proper engine operation during the test, one of the ARB inspection team members would observe vehicle driver performance during the test (to ensure that the engine was accelerated correctly) while the second team member observed emitted smoke and collected test measurements. Before performing an automated smoke measurement, ARB staff would conduct a visual observation of vehicle smoke during a rapid engine acceleration (with the transmission in neutral). Vehicles emitting significant smoke during this screening test, would be subject to subsequent automated testing; smoke-free vehicles would be released without further action. Based on the smoke opacity values measured during the automated test (on vehicles failing the visual screening test), the vehicle would then either be released without further action or issued a smoke citation if measured smoke levels exceeded applicable standards. This same procedure is applicable to the proposed HDVIP. While the smoke measurement algorithm will be revised to SAE J1667 specifications for the proposed HDVIP and PSIP, this change is transparent to the vehicle operator and the ARB inspection staff and does not affect the basic operational steps required to perform an inspection.

Under the original HDVIP, excessive smoke citations were issued to all vehicles with measured smoke levels above applicable standards. These citations carried a civil penalty designed to promote quick and effective vehicle repairs. Initial citations carried a basic penalty of $800, $500 of which was waived if repairs were completed within 45 days of issuance. Issuance of a second citation within one year carried a basic penalty of $1,800. In instances of further citations (issued within one year of a second citation) a CHP officer-assisted out-of-service order for the vehicle could be issued. The citation and penalty structure for the proposed HDVIP is identical.

6.3 PROGRAM STAFFING AND ADMINISTRATIVE COSTS

ARB staffing requirements and administrative costs to implement the proposed HDVIP and PSIP are well quantified as a result of the implementation and administration of the original HDVIP from November 1991 through October 1993. The staffing requirements of the 1991-93 HDVIP and those of the J1667-based HDVIP and PSIP are expected to be identical. Although enforcement of the HDVIP has been suspended since October of 1993, the staff responsible for administration of the program has been retained continuously since that time and has been performing alternative duties such as reformulated fuels (gasoline and diesel) support work, voluntary HDVIP and PSIP administration, industry assistance and outreach seminars, and research testing for the proposed HDVIP and PSIP. Therefore, program staffing is currently in place and ready to implement the revised HDVIP following adoption of the proposed regulations and their subsequent registration in accordance with State law.

The only significant procedural change between the previous and proposed HDVIP is the test measurement algorithm. Accordingly, the two programs are equivalent from a staffing demand standpoint. Strip chart recorders will not be necessary under the proposed program (as was the case under the original HDVIP) and, as a result, program staff will be able to increase the vehicle inspection volume or perform alternative duties due to the elimination of time demands associated with chart recorder setup and operation. The implementation of the PSIP will impose an additional annual audit requirement on top of normal HDVIP functions, but it is expected that these audit demands can be assimilated into the duties of current HDVIP program staff.

From a capital cost standpoint, the proposed HDVIP and PSIP will also be similar to the original HDVIP. New smokemeters capable of measuring smoke in accordance with the SAE J1667 test procedure will be required to replace the existing SAE J1243 smokemeters used under the original program. However, the J1243 analyzers have been fully depreciated and thus do not impose a capital loss on the proposed program. As indicated above, strip chart recorders will no longer be required. These also have been fully depreciated and have no significant salvage value. Remaining inspection equipment demands (e.g., specially equipped mobile testing vans, portable computers) are expected to be equivalent between the original and proposed HDVIP. The implementation of the PSIP imposes no additional capital demands on the ARB since HDVIP equipment will be used to administer both the HDVIP and PSIP. The PSIP does, however, impose both labor and capital costs on fleet facilities subject to the program and these costs were not associated with the original HDVIP.

The following subsections summarize estimates for each of these administrative and capital cost elements.

6.3.1 ARB Staffing Costs

Current ARB HDVIP staff consists of field inspectors, field supervisors, and central office support supervision. The actual cost of ARB staff can vary within a specific personnel classification by approximately 10 percent due to turnover rates, length of service, etc. To address this variation and allow overall estimates of ARB staffing cost to be developed, the costs used for this analysis are the median costs for the applicable personnel classification. Furthermore, the assumed costs are fully burdened, in that they reflect not only salary, but the cost of benefits, phones, rent, travel, training, supplies, and all other overhead.

The ARB employs 18 staff classified as Air Resources Field Representative II's to conduct vehicle inspections and HDVIP- and PSI-related work. These inspectors are assigned to one of two field supervisors. One field supervisor oversees northern California inspection teams and the other oversees the southern California teams. Both field supervisors are classified as Air Resources Field Representative III's. The median hourly cost (fully-burdened) for the Air Resources Field Representative II and III classifications is $40.17 and $43.04 respectively. Using these hourly costs, the estimated annual cost of ARB field staff for the HDVIP and PSIP is $1.68 million (assuming 40 hours per week for 52 weeks per year, or 2,080 hours annually).

Central office staff assigned to the HDVIP and PSIP consist of one Air Resources Technician I, two Air Resources Technician II's, three Associate Air Resources Engineers, three Associate Air Pollution Specialists, two Senior Air Pollution Specialists, one Supervising Air Pollution Specialist, and one Office Technician. These staff perform the myriad of administrative duties associated with the HDVIP and PSIP including: data entry and database maintenance, citation tracking and clearance, all liaison duties with vehicle owners and industry (excluding actual vehicle inspections), and regulatory development

and program review. Median hourly costs (fully-burdened) for each of the included personnel classifications are as follows:

Air Resources Technician I	**$26.67**
Air Resources Technician II	**$30.08**
Associate Air Resources Engineer	**$46.55**
Associate Air Pollution Specialist	**$44.86**
Senior Air Pollution Specialist	**$52.13**
Supervising Air Pollution Specialist	**$56.29**
Office Technician	**$28.35**

Using these median hourly cost estimates, total ARB annual staffing costs for the proposed HDVIP and PSIP are estimated to be $2.83 million This cost applies to a fully staffed program of nine field inspection teams and the associated supervisory and central office support.

In addition to these direct staffing costs, the ARB estimates an additional need for $50,000-$100,000 annually for contractual CHP support. This estimate is based on costs incurred during the 23 month period of administration of the original HDVIP where CHP support was required for stopping and directing vehicles to ARB test areas. The same support services will be required under the proposed HDVIP (the PSIP imposes no additional CHP staffing demands). Therefore, an average annual CHP support cost of $75,000 is expected, bringing total annual ARB staffing expenditures to $2.95 million

6.3.2 <u>Fleet Inspection Labor Costs</u>

Implementation of the fleet PSIP will impose labor costs on affected fleets. These costs were not reflected in the original HDVIP program and thus represent new costs to the regulated community. To estimate the impact of PSIP annual inspection requirements on

affected fleets, it was assumed that each vehicle inspection would be accomplished by two fleet personnel over a five minute period. No net vehicle transport labor time or vehicle out-of-service time was assumed for the inspection since it is expected that all PSIP inspections will be accomplished during routine out-of-service periods (e.g., oil changes, periodic maintenance). A fully burdened hourly labor cost of $50 was assumed for each fleet inspector.

Estimates of the number of fleets and fleet vehicles covered by the PSIP program were developed using the ARB's MVEI7G emissions inventory model and the U.S. Department of the Census' 1992 Census of Transportation: Truck Inventory and Use Survey (TIUS). The ARB's MVEI7G model estimates a total heavy duty diesel vehicle population of 570,561 vehicles in 1999 and 777,214 vehicles in 2010. ARB has previously estimated that 19 percent of these vehicles are out-of-state registries and, therefore, exempt from PSIP requirements. On this basis, the net California-registered heavy duty diesel vehicle population is estimated to be 462,164 in 1999 and 629,543 in 2010.

TIUS data indicate that 63.1 percent of heavy duty vehicles operate in fleets of two or more. TIUS also indicates that there are an average of 31.6 vehicles in each such fleet. Using these data, the total number of fleet vehicles subject to the PSIP in 1999 and 2010 is estimated to be 291,397 and 396,939 respectively. The total number of PSIP-covered fleets is estimated by dividing the number of covered fleet vehicles by the average fleet size, resulting in an estimate of 9,217 covered fleets in 1999 and 12,555 covered fleets in 2010.

Estimating PSIP fleet inspection labor costs is complicated by the fact that not all fleets will elect to perform inspections using "in-house" labor[2] and equipment. Some fraction of fleet

[2] In-house labor (or in-house staff) refers to staff directly employed and compensated by the fleet owner to

owners will opt instead to contract with independent testing services. A number of such services have been established since the implementation of the original HDVIP. Based on these established services, the average cost for contractual testing ranges from $45-$75 per inspection. Since the estimated cost for a smokemeter capable of measuring smoke in accordance with SAE J1667 procedures is estimated to be approximately $5,000 (on average) and have an average useful life of 5 years, a median contractual service testing cost of $60 per vehicle implies that in-house inspection is more economical than contractual inspection only when fleet size exceeds 16 vehicles. The TIUS data indicate that approximately 45.7 percent of heavy duty vehicle fleets are larger than this size cutoff.

On the basis of this analysis, 45.7 percent of fleets (each averaging 31.6 vehicles in size) should find it more economical to purchase smokemeters and perform testing using in-house staff. The remaining fleet vehicles can be more economically tested using contractual inspection services. Disaggregating the total heavy duty diesel fleet and vehicle population estimates by these fractions yields the following estimates:

4,216 fleets self-testing 133,287 vehicles in 1999, and
5,001 fleets having 158,110 vehicles tested contractually in 1999.

5,743 fleets self-testing 181,563 vehicles in 2010, and
5,001 fleets having 215,376 vehicles tested contractually in 2010.

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perform PSIP vehicle inspections. This terminology is used to distinguish those fleets that purchase smokemeters and assign staff to perform inspection duties from those fleets that hire a contractual inspection service.

The net inspection labor costs for fleets opting to use contractual services are near zero. Testing contractors do incur costs associated with inspection labor, but these costs accrue as capital expenditures to affected fleets and are thus accounted for in Section 6.3.4 below.

Before a total estimate of fleet inspection labor costs can be developed for those fleets performing inspections using in-house staff, the number of vehicle reinspections due to smoke inspection failure must be added to the number of vehicles initially inspected. As described in Section 6.5.1 below, the estimated failure rates for the HDVIP and PSIP is 13.1 percent in 1999 and 8.6 percent in 2010, resulting in an estimated 17,404 in-house PSIP retests in 1999 and 15,524 in-house retests in 2010. Combining these retest estimates with estimates for the number of initial inspections, the per-vehicle inspection time, the number of fleet personnel required to perform an inspection, and the hourly cost of labor as presented above, the total fleet labor cost due to HDVIP and PSIP implementation is estimated to be \$1.26 million in 1999 and \$1.64 million in 2010, calculated as follows:

$$\text{labor cost in } 1999 = 2 \text{ staff} \times \$50/\text{hr} \times 150{,}691 \text{ inspections} \times 5/60 \text{ hrs/inspection}$$

$$= \$1.26 \text{ million}$$

$$\text{labor cost in } 2010 = 2 \text{ staff} \times \$50/\text{hr} \times 197{,}086 \text{ inspections} \times 5/60 \text{ hrs/inspection}$$

$$= \$1.64 \text{ million}$$

6.3.3 <u>ARB Capital Costs</u>

Both the HDVIP and PSIP require specialized equipment. Although the only specific equipment required to perform an inspection is a smokemeter capable of measuring smoke in accordance with SAE J1667 procedures, additional equipment such as specially outfitted vehicles, portable computers, and meteorological measurement tools are required to allow this testing to be performed effectively and efficiently in any field location. Required equipment is identical to that used for the original HDVIP, except that smokemeter performance specifications must now adhere to the SAE J1667 test procedure and the strip chart recorders required for previous HDVIP testing will no longer be needed. Given that all equipment used in the original HDVIP has now been fully depreciated, no net capital loss is assumed for either the SAE J1243 smokemeters or strip chart recorders which will not be used under the proposed program. Salvage value is also assumed to be insignificant relative to total program costs. Finally, ARB administration of the PSIP adds no capital costs beyond those expected under the proposed HDVIP since administrative functions required under both will be accomplished with the same equipment which would be required for the HDVIP alone.

The unit cost of SAE J1667-compliant smokemeters is estimated to be approximately $5000. ARB will require one smokemeter per inspection team plus one backup unit per five inspection teams to ensure that inspections are not curtailed during meter downtime. Thus, with nine fully equipped inspection teams, the total ARB smokemeter need is 11 units, necessitating a capital outlay of approximately $55,000. A straight line depreciation of this cost over the estimated five year smokemeter life results in an estimated annual capital cost of $11,000.

A moderately powered portable computer and durable printer are required for each inspection team to store and report inspection results, issue citations, and query historical compliance data for target inspection vehicles. The portable computer systems purchased for the original HDVIP have been fully depreciated and have negligible salvage value and, therefore, are not assumed to influence ARB capital costs under the proposed HDVIP and PSIP. In today's market, even the cost of high-end computers (substantially overpowered for inspection team needs) is less than that expended for the Intel 386-based machines and dot-matrix printers used by ARB staff during the original HDVIP. Using an estimated $2,000 per moderately powered system (such as a Pentium-based 166 MHZ or 200 MHZ machine) with a reliable dot-matrix printer (to allow impact-based multiple copy printing), the overall capital costs for the nine inspection teams is $18,000. A straight line depreciation of this cost over the estimated five year equipment life results in an estimated annual capital cost of $3,600.

It is certainly likely that computing costs per unit performance measure will continue to decline over time as has been the case historically. Nevertheless, it is also the case that performance demands continue to increase and more sophisticated equipment is needed to accommodate advanced software applications. There is no reason to expect that data processing demands of HDVIP and PSIP staff will not evolve in a similar fashion, advancing the computer power needs of the program over time. Therefore, while costs could be expected to decline over time for static computing power, it is more likely that increasing power demands will offset this cost reduction and result in similar future computing costs. For this reason, no reduction in computer costs over time is assumed in this analysis.

Three central office computers are required for data entry, database maintenance, statistical analysis of program data, and report preparation as well as general

administrative duties. A high-end system with high-end laser printer and associated software is estimated to cost approximately $4,000 per unit. Three units therefore necessitates a total capital outlay of $12,000. A straight line depreciation of this cost over the estimated five year equipment life results in an estimated annual capital cost of $2,400.

Finally, based on costs incurred under the original HDVIP, the capital outlay for specially outfitted vehicles (i.e., modified for equipment storage, "office" area, computer and smokemeter power inverters, etc.) needed by HDVIP inspection personnel is approximately $35,000 per unit. For nine inspection teams, the net capital outlay is estimated to be $315,000, or $31,500 per year assuming a straight line depreciation over the ten year estimated useful life of the equipment. The salvage value of existing equipment (approximately $1,000 per vehicle) is minor relative to total annual program costs.

Summing these component costs, total ARB annualized capital costs are estimated to be $48,500 as follows:

Smokemeters	**$11,000**
Field Computer Systems	**$3,600**
Office Computer Systems	**$2,400**
Inspection Vans and Equipment	**$31,500**

	$48,500

6.3.4 Fleet Capital Costs

Under the PSIP, covered fleets will be either be required to purchase and operate smokemeters capable of measuring smoke in accordance with the SAE J1667 procedure or, alternatively, contracting with private testing services to have the required PSIP inspections performed. While it is possible that a fraction of covered fleets own or would purchase such equipment independent of PSIP requirements, it is not possible to estimate

the magnitude of this fraction. Therefore, it is assumed that each of the fleets covered by the PSIP will be required to either purchase a J1667-compliant smokemeter or contract for inspection services.

As discussed in Section 6.3.2 detailing fleet labor costs, 9,217 fleets are estimated to be subject to the PSIP in 1999. The number of covered fleets is estimated to increase to 12,555 in 2010. Of these, 4,216 fleets were estimated to perform in-house testing in 1999 and 5,743 fleets were estimated to perform in-house testing in 2010. Each of these fleets will require at least one J1667-compliant smokemeter. It is likely that some of the larger fleets will require multiple smokemeters to accommodate their entire covered vehicle population. According to the TIUS data used to estimate PSIP fleet populations, approximately 18.7 percent of covered fleets have more than 100 vehicles. Using this fraction as an estimate of the fraction of fleets that will need to purchase two smokemeters to satisfy PSIP testing requirements, an overall average of 1.187 smokemeters per in-house testing fleet will be required under the PSIP (0.187 times 2 plus 0.813 times 1).

As indicated in Section 6.3.3, J1667-compliant smokemeters are estimated to cost approximately $5,000 per unit (on average). Since 4,216 fleets are expected to purchase an average of 1.187 smokemeters each in 1999, the total capital outlay in 1999 is estimated to be $25.02 million. By 2010, an additional 1,527 fleets (5,743 fleets in 2010 minus 4,216 fleets in 1999) will need to purchase an average of 1.187 smokemeters for an additional capital outlay of $9.06 million. A straight line depreciation of these costs over the estimated five year equipment life results in an estimated annual PSIP capital costs due to smokemeter purchase of $5 million in 1999 and $6.82 million in 2010.

Fleets which contract with private testing services to perform PSIP inspections will incur annual capital costs for these services. As detailed in Section 6.3.2, it is estimated that

158,100 vehicles will be subject to contractual testing in 1999 and 215,376 vehicles will be subject to contractual testing in 2010. On the basis of the PSIP failure rates of 13.1 percent in 1999 and 8.6 percent in 2010 (as estimated in Section 6.5.1), an additional contractual inspection load of 20,646 retests in 1999 and 18,415 retests in 2010 is expected. Combining these retest estimates with the estimates for the number of initial inspections and the per-inspection cost estimate of $60 (as described in Section 6.3.2), the total fleet capital cost outlay for contractual PSIP inspections is estimated to be $10.73 million in 1999 and $14.03 million in 2010.

6.4 FAILURE RATES FROM THE RANDOM TRUCK OPACITY SURVEY

In addition to the HDVIP and PSIP administrative costs estimated in Section 6.3, vehicle owners will also incur costs due to vehicle repair, citation clearance, lost time, and improved maintenance practices. Each of these costs depends either on the number of vehicles which fail HDVIP or PSIP inspections or the risk of inspection failure, both of which are defined by the HDVIP and PSIP failure rate. Therefore, an estimate of the inspection program failure rates in 1999 and 2010 is required before the additional vehicle owner costs can be defined. This section details the methodology by which the required failure rate estimates were developed and presents the resulting estimates.

6.4.1 The Random Truck Opacity Survey

Section 3.3 describes the Random Truck Opacity Survey[3] conducted by the ARB between August and November of 1996. Because the Random Truck Opacity Survey data is critical

[3] Although formally known as the Random Truck Sampling Survey, the test program measured smoke emissions from all types of in-use heavy duty diesel vehicles operating on California roadways, including

to the estimation of heavy duty diesel vehicle failure rates under the proposed HDVIP and PSIP (and thus critical to the estimation of vehicle repair costs, etc.), background material on the survey is reproduced here so that a full understanding of the failure rate analysis is possible.

The Random Truck Opacity Survey (RTOS) included the application of the SAE J1667 snap-acceleration smoke test procedure to randomly selected heavy duty diesel vehicles in an effort to develop a profile of heavy duty diesel vehicle smoke characteristics in California. Through this study, SAE J1667 smoke test results were obtained for a usable sample of 1002 vehicles (as described in Section 6.4.2 below, testing results for 190 vehicles were unusable due to incomplete or erroneous data). Tables 6-1 and 6-2 present the breakdown of test engines by manufacturer, model year group, and size category. Table 6-3 is a reproduction of Table 3-1, which presents a breakdown of Random Truck Opacity Survey testing locations.

All smoke testing performed under the Random Truck Opacity Survey was conducted in accordance with SAE J1667 procedures (see Appendix A). As specified under the J1667 test procedure, data other than actual smoke test results are needed in order to make a standardized determination of emitted smoke since both smoke production rates and smoke measurements can be dependent on test conditions. Smoke production rates, which are sensitive to combustion

TABLE 6-1. DISTRIBUTION OF HHDDV[1] IN THE RTOS BY MANUFACTURER

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buses.

Engine Make	Model Year Group					Total Tested	Percent Tested
	Pre-198 0	1980-83	1984-87	1988-90	1991+		
Caterpilla r	6	4	30	34	81	155	26.2
Cummins	47	46	109	63	73	338	57.1
DDC	3	1	6	10	64	84	14.2
Hino	0	0	0	1	1	2	0.3
Mack	1	0	0	1	5	7	1.2
Navistar	0	0	1	0	1	2	0.3
Unknown	0	0	0	0	4	4	0.7
All Makes	57	51	146	109	229	592	100.0

[1] Heavy-heavy duty diesel vehicles.

TABLE 6-2. DISTRIBUTION OF MHDDV[1] IN THE RTOS BY MANUFACTURER

Engine Make	Model Year Group					Total Tested	Percent Tested
	Pre-1980	1980-83	1984-87	1988-90	1991+		
Caterpillar	3	7	12	15	27	64	15.6
Cummins	24	40	76	39	62	241	58.8
DDC	1	1	10	4	18	34	8.3
Ford	0	0	3	2	0	5	1.2
Hino	0	0	3	4	3	10	2.4
Iveco	0	0	0	2	0	2	0.5
Mack	0	0	4	5	3	12	2.9
Navistar	0	0	1	2	3	6	1.5
Nissan	0	0	0	0	1	1	0.2
Volvo	0	0	0	0	2	2	0.5
White	0	0	1	0	0	1	0.2
Unknown	1	2	6	8	15	32	7.8
All Makes	29	50	116	81	134	410	99.9

[1] Medium-heavy duty diesel vehicles.

TABLE 6-3. DISTRIBUTION OF RTOS TEST LOCATIONS

Test Location	Model Year Group					Total Tested	Percent Tested
	Pre-198 0	1980-83	1984-87	1988-90	1991+		
Northern California Locations							
Antelope	15	8	29	16	30	98	9.8
Cordelia	10	6	19	15	24	74	7.4
Los Banos	0	3	9	2	7	21	2.1
Northern Total	25	17	57	33	61	193	19.3
Southern California Locations							
Cache Creek	0	0	0	0	5	5	0.5
Castaic	5	7	22	26	46	106	10.6
Desert Hills	5	7	12	9	18	51	5.1
Grapevine	0	5	15	7	14	41	4.1
Rainbow	16	17	44	34	70	181	18.1
San Onofre	29	35	96	61	120	341	34.0
Temecula	2	6	5	9	8	30	3.0
Winterhaven	4	7	11	11	21	54	5.4
Southern Total	61	84	205	157	302	809	80.7
All Locations							

Sample Total	86	101	262	190	363	1,002	100.0

air/fuel ratio, can vary with meteorological conditions affecting air density. Even under identical meteorological conditions, smoke measurement, which relies on a determination of the degree of light absorption and scattering, is sensitive to the distance the transmitted light must pass between its source and a detector (this transmission distance is known as the optical path length). Because of this dependency, two engines with identical smoke generation rates but different diameter exhaust stacks will generate different opacity readings (using full flow end-of-line smokemeters). The SAE J1667 test procedure includes corrections to address both phenomena and produce standardized smoke measurements.

Data required to perform the necessary J1667 smoke measurement corrections include the effective optical path length to correct for different exhaust stack sizes and meteorological parameters to correct for differences in ambient air density. For full flow end-of-line type smokemeters, the effective optical path length is generally equivalent to exhaust stack diameter. For partial flow sampling smokemeters, the effective optical path length for smoke measurement is a function of the meter's internal sampling chamber. However, partial flow sampling smokemeters require the user to input the stack diameter for the test vehicle and actual smoke measurements are internally corrected to this input "path length" prior to reporting. As a result, both end-of-line and partial flow smokemeters report smoke measurements based on the stack diameter of the test vehicle. To correct for differences in ambient air density, parameters such as dry and wet bulb temperatures and barometric pressure must be measured at the time of testing. The Random Truck Opacity Survey included collection of all such required data as well as additional data to classify the

subject test vehicle and engine population according to gross vehicle weight rating (GVWR) class and model year.

6.4.2 Corrections to the Random Truck Opacity Survey Database

Before the raw data collected under the Random Truck Opacity Survey could be analyzed to estimate HDVIP and PSIP failure rates, optical path length and ambient conditions adjustments were undertaken to construct a database consistent with SAE J1667 test procedure requirements. To undertake these corrections, a minimum set of data was required which included: measured opacity, vehicle stack diameter, engine horsepower, ambient temperature, and barometric pressure. Additionally, parameters such as engine model year and GVWR class were needed to properly discriminate trends in the required failure rate analysis.

The Random Truck Opacity Survey was designed to collect data for all required SAE correction and failure rate analysis parameters. Nevertheless, there were cases when a complete set of data was not collected for each vehicle surveyed. Reasons for incomplete data collection vary, but include such influences as data entry error, missing engine and vehicle tags (from which GVWR and model year are determined), measurement equipment malfunction, etc. In total, 1192 vehicles were sampled under the Random Truck Opacity Survey. Test records for 190 of these vehicles were eliminated through quality assurance checks which revealed missing or erroneous smoke measurement, vehicle or engine identification, effective optical path length, or meteorological data. Some of these records could have been retained despite the lack of valid meteorological data since the Random

Truck Opacity Survey was limited to low altitude test sites where the degree of meteorological influence is generally expected to be minor. Nevertheless, these records were eliminated from further analysis to ensure adherence to SAE J1667 test procedures. As a result, a total of 1002 usable test records were collected.

Of the 1002 available Random Truck Opacity Survey records, only about 54 percent included specific engine model year data. The remaining 46 percent of test records did not indicate the applicable test engine model year due to missing engine labels, data acquisition errors, or data entry errors. These 46 percent did however include data on the model year of the subject test vehicle. To maximize available analysis data, a comparison of the 54 percent of test records (538 records) with both vehicle and engine model year data was made. Ninety (90) percent of these records (484 records) indicated a difference of no more than one year between the two indicated model years. Forty-seven (47) percent indicated identical vehicle and engine model years, 42 percent indicated an engine one model year older than the vehicle, and 1 percent indicated a vehicle one year older than the engine. Based on this observed similarity of engine and vehicle model years, test record vehicle model year was used as a surrogate for test engine model year when the latter was not available.

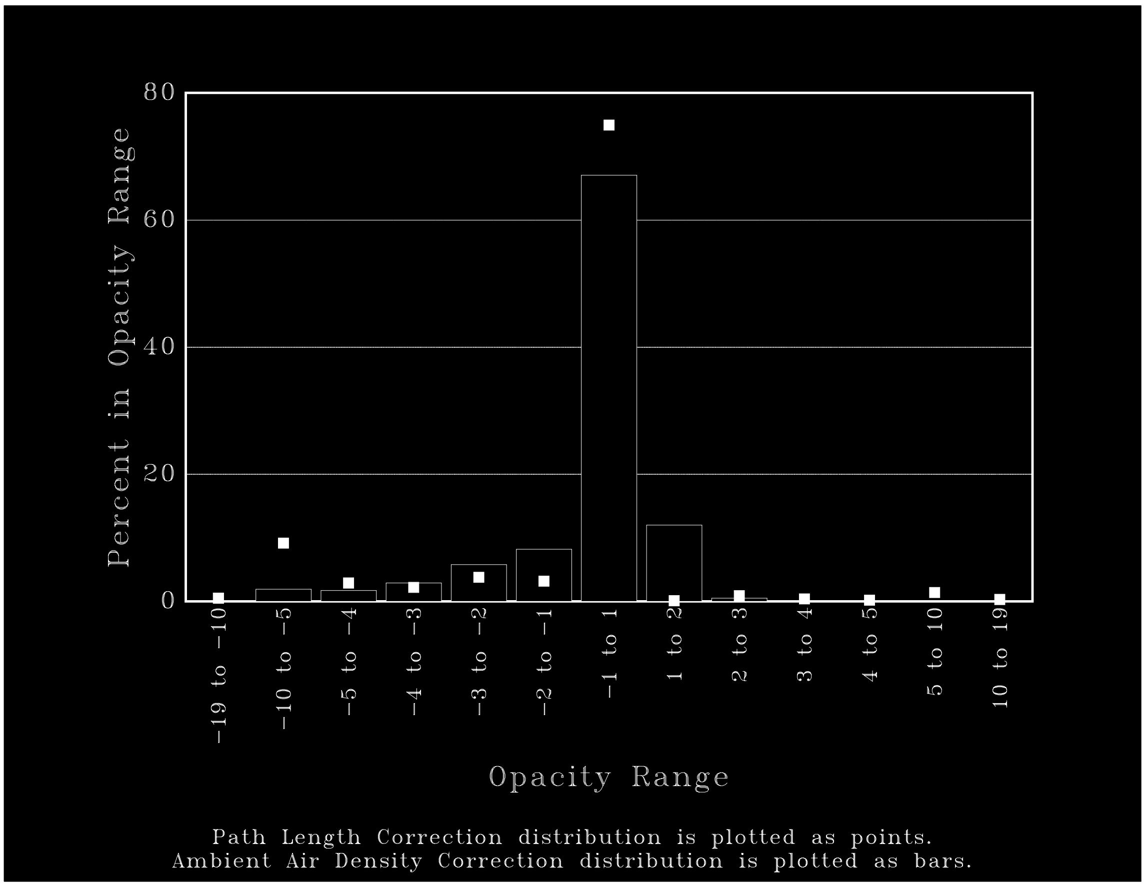
The measured smoke readings on all usable Random Truck Opacity Survey test records were corrected to their SAE J1667 standard optical path length and standard ambient test condition equivalents. J1667 optical path length standards vary between 2 and 5 inches depending on engine horsepower. About two-thirds of the smoke test records included a specified engine horsepower. For the other one-third of test engines, a 5 inch standard optical path length (applicable to engines of 301 horsepower and above) was selected if the

test engine was identified as being in the heavy-heavy duty class and a 4 inch standard optical path length (applicable to engines of 201 to 300 horsepower) was selected if the test engine was identified as being in the medium-heavy duty class.

Smokemeters from three different manufacturers were used in the Random Truck Opacity Survey. Two were full flow end-of-line smokemeters such that the effective optical path length during testing was equal the measured diameter of the vehicle exhaust stack. The third smokemeter was a partial flow sampling-type meter with an internal effective optical path length of 100 millimeters. However, the partial flow meter performed an internal stack diameter correction so that the effective path length of reported smoke measurements was equal to the test vehicle stack diameter. Therefore, the measured exhaust stack diameter was used as the optical path length of the uncorrected smoke measurements for all Random Truck Opacity Survey test records.

Figure 6-1 presents the distribution of the magnitude of J1667 optical path length corrections applied to Random Truck Opacity Survey data. Negative corrections indicate that the corrected opacity is less than the measured opacity. As indicated, about 75 percent of all Random Truck Opacity Survey measurements were corrected by 1 opacity percent or less, with 89 percent of measurements corrected by 5 opacity percent or less. The remainder of

FIGURE 6-1. DISTRIBUTION OF OPACITY CORRECTIONS



corrections mostly decrease measured opacity by 5 to 10 percentage points. Corrections in this range are generally indicative of large diameter exhaust stack measurements being corrected to smaller J1667 standard stack diameters (most notably 5 inch measured path lengths being corrected to 4 inch standard path lengths at moderate to high opacity levels).

Following the application of the standardized optical path length correction, an additional correction designed to account for ambient condition (i.e., air density) differences was applied to each test record as prescribed by the SAE J1667 test procedure. Under SAE J1667, all measured opacities are corrected to a reference dry air density of 0.0722 pounds-mass per cubic foot. While this ambient correction can be substantial for large variations in air density, the elevation and temperature ranges of the ARB Random Truck Opacity Survey were fairly restricted as indicated by the distribution of applied corrections shown in Figure 6-1. Sixty-seven (67) percent of ambient corrections were 1 opacity point or less, 87 percent were 2 opacity points or less, and 98 percent were 5 opacity points or less. As was the case with the path length correction described above, negative corrections indicate an adjustment to reduce measured opacity.

6.4.3 Expected HDVIP and PSIP Failure Rates

The corrected Random Truck Opacity Survey data was analyzed to determine the failure rates which can be expected upon enforcement of the cutpoints documented in Chapter 4. Since the failure rate for a specific vehicle class can be expected to increase (especially in the absence of an active smoke enforcement program) as engines age and deteriorate, the form of the failure rate deterioration function must be estimated to accurately forecast expected failure rates for different smoke enforcement program evaluation years. To estimate this deterioration function, the

Random Truck Opacity Survey data was analyzed by vehicle class and engine model year to determine if statistical trends in failure rate with engine age were observable.

In the initial analysis of the Random Truck Opacity Survey database, it was apparent that the sample size of certain model year engines was not sufficient to isolate opacity trends. As indicated in Table 6-4, sample sizes for model years 1984 through 1996 are fairly consistent and sufficiently large to accommodate individual analysis. Samples for the remaining model years are not of sufficient size to allow age-based trends in emitted smoke to be distinguished from other potential sources of variability. Nevertheless, data for these older engines is important, and an alternative analysis approach based on the aggregation of older model years was employed.

1980 and earlier heavy duty diesel engines utilize similar, relatively unsophisticated, mechanically controlled technology and have accumulated sufficient mileage such that virtually all have undergone multiple engine rebuilds and can be expected to behave similarly from a smoke emissions standpoint. 1981 through 1983 model year engines represent the last group of heavy duty diesel engines certified for sale under a steady-state emissions testing procedure. All were certified to the same set of standards and will have accumulated similar mileages and, therefore, should possess similar smoke emissions characteristics. Based on these similarities, all 1980 and earlier model year test records were aggregated into one group and all 1981 through 1983 model year test records were aggregated into a second group. Both groups were treated in the aggregate for statistical analysis purposes. Because of their very low sample size, all 1997 vehicles in the Random Truck Opacity Survey database were aggregated with 1996 vehicles for analysis. This

aggregation process resulted in fairly consistent sample sizes across all analysis "model years" as shown in Table 6-4.

Before proceeding with failure rate model construction using the Random Truck Opacity Survey database an evaluation was undertaken to determine whether a single failure rate model could be developed for all test vehicles or whether a distinct model would be required for various subsets of the heavy duty diesel vehicle fleet. Figures 6-2 through 6-11 present observed opacity distributions (after the application of the smoke measurement standardization procedures discussed in Section 6.4.2 above) for various model year groupings of the

TABLE 6-4. SAMPLE SIZES FROM THE RANDOM TRUCK OPACITY SURVEY

Sample Sizes Before Aggregation					
Model Year	HHDDV	MHDDV	Model Year	HHDDV	MHDDV
1968	1	0	1983	18	17
1969	1	1	1984	36	34
1970	3	2	1985	38	30
1971	1	2	1986	33	25
1972	3	0	1987	39	27
1973	2	2	1988	38	26
1974	4	2	1989	45	28
1975	2	3	1990	26	27
1976	3	0	1991	27	17
1977	13	5	1992	40	20
1978	11	6	1993	36	23
1979	13	6	1994	38	24
1980	15	13	1995	59	30
1981	11	8	1996	26	19
1982	7	12	1997	3	1
Sample Sizes after Aggregation					
Model Year	HHDDV	MHDDV	Model Year	HHDDV	MHDDV
Pre-1980	57	29	1990	26	27
1980-1983	51	50	1991	27	17
1984	36	34	1992	40	20
1985	38	30	1993	36	23
1986	33	25	1994	38	24
1987	39	27	1995	59	30
1988	38	26	1996-1997	29	20
1989	45	28			

FIGURE 6-2. OPACITY DISTRIBUTION FOR PRE-1980 HHDDV

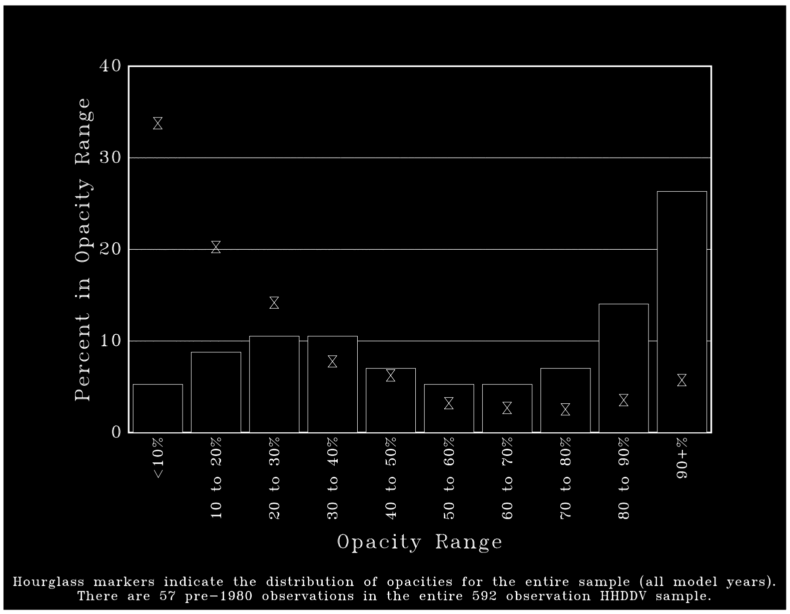
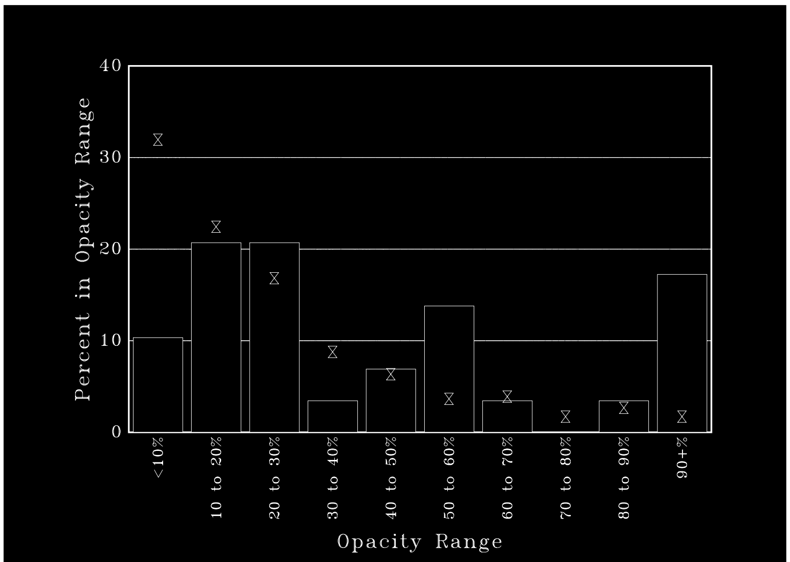


FIGURE 6-3. OPACITY DISTRIBUTION FOR PRE-1980 MHDDV



Hourglass markers indicate the distribution of opacities for the entire sample (all model years).
There are 29 pre-1980 observations in the entire 410 observation MHDDV sample.

FIGURE 6-4. OPACITY DISTRIBUTION FOR 1980-83 HHDDV

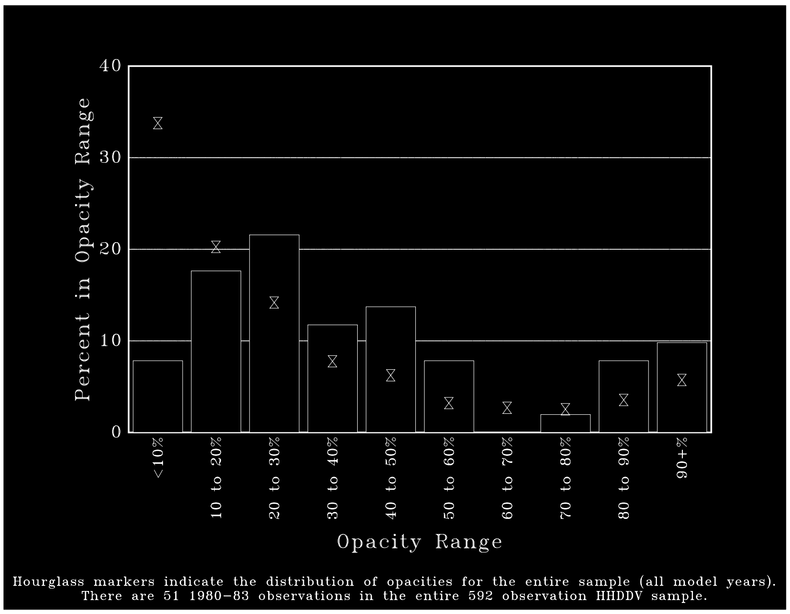
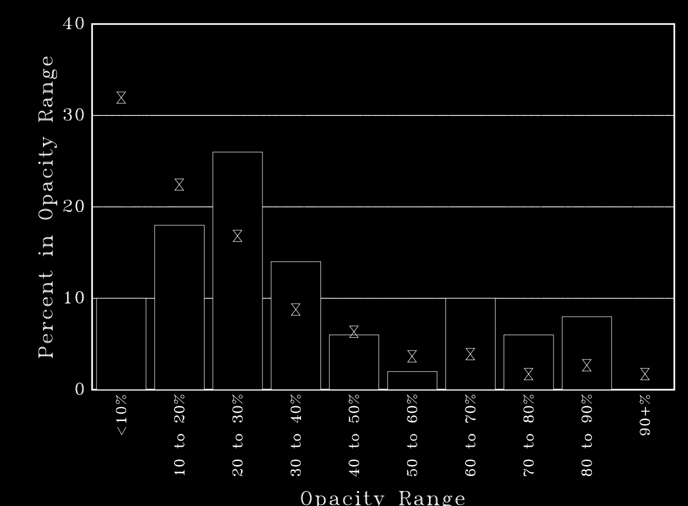
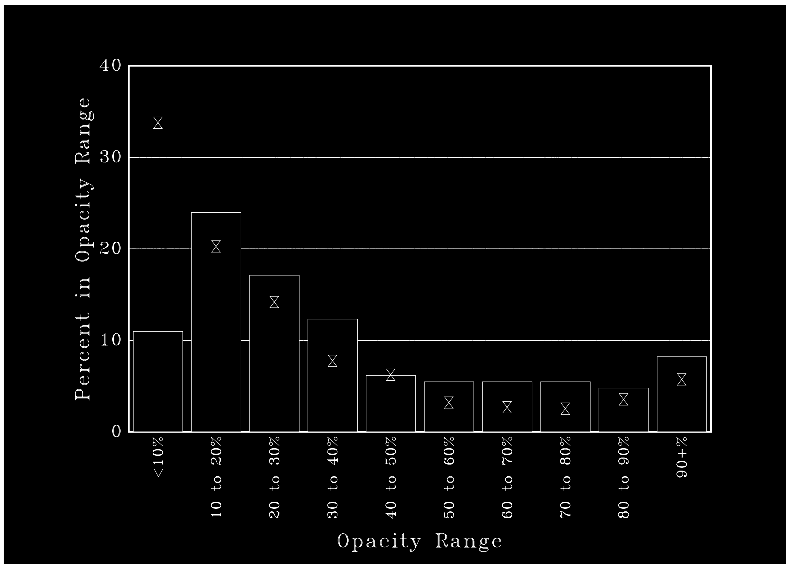


FIGURE 6-5. OPACITY DISTRIBUTION FOR 1980-83 MHDDV



Hourglass markers indicate the distribution of opacities for the entire sample (all model years). There are 50 1980–83 observations in the entire 410 observation MHDDV sample.

FIGURE 6-6. OPACITY DISTRIBUTION FOR 1984-87 HHDDV



Hourglass markers indicate the distribution of opacities for the entire sample (all model years). There are 146 1984-87 observations in the entire 592 observation HHDDV sample.

FIGURE 6-7. OPACITY DISTRIBUTION FOR 1984-87 MHDDV

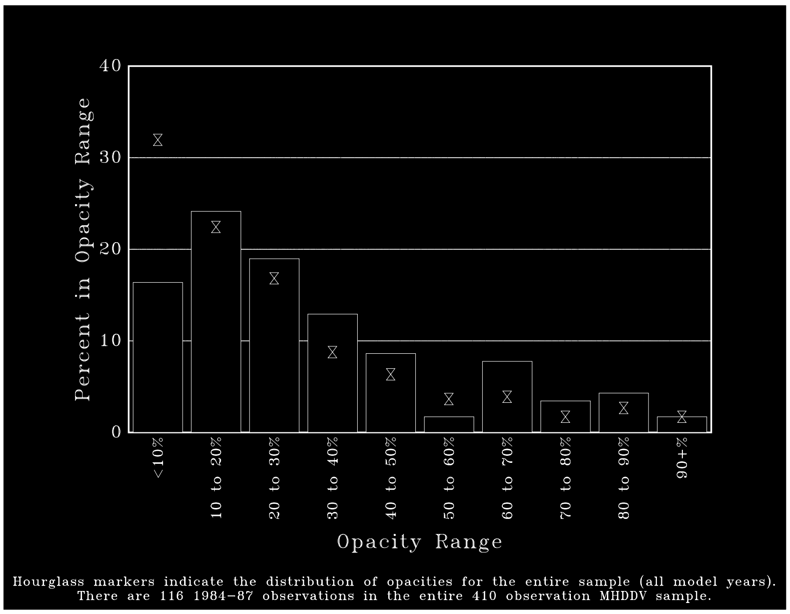


FIGURE 6-8. OPACITY DISTRIBUTION FOR 1988-90 HHDDV

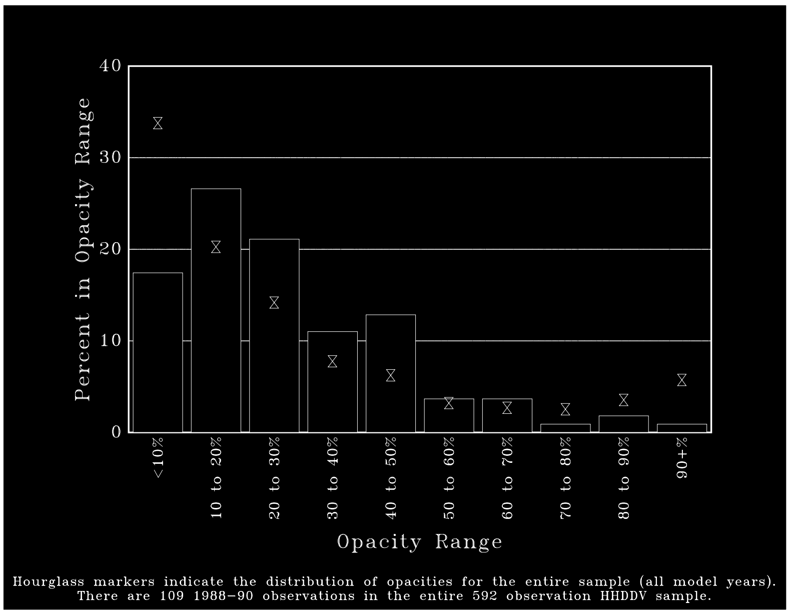


FIGURE 6-9. OPACITY DISTRIBUTION FOR 1988-90 MHDDV

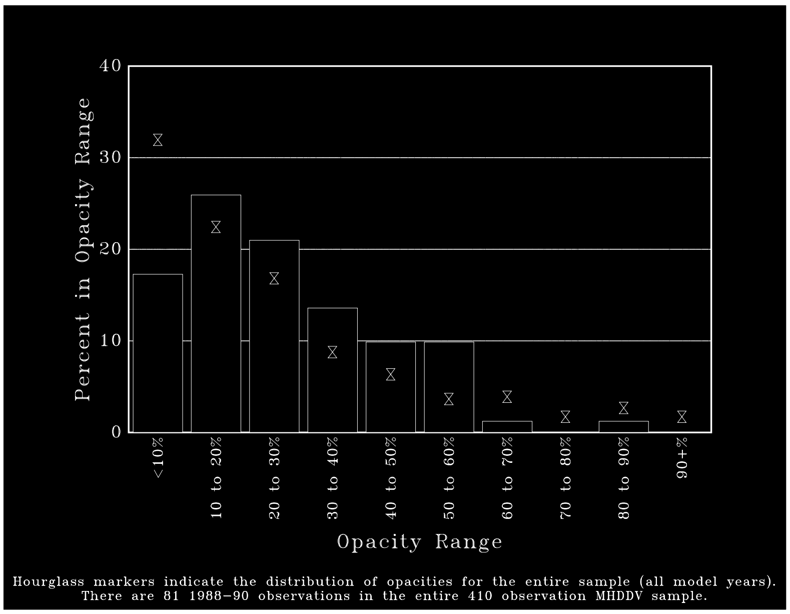
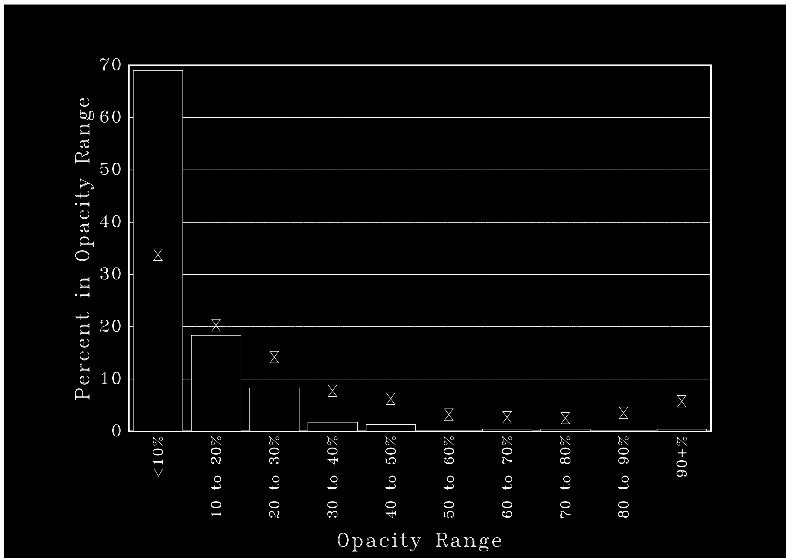
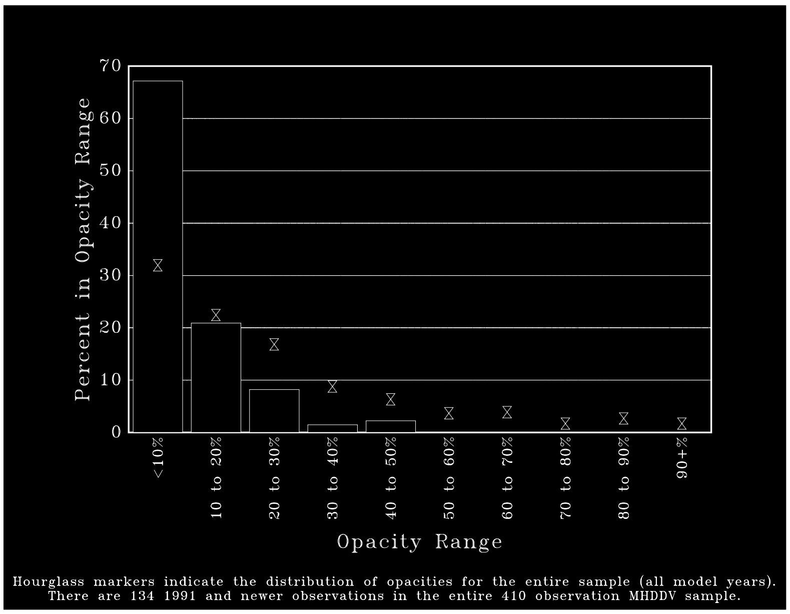


FIGURE 6-10. OPACITY DISTRIBUTION FOR 1991+ HHDDV



Hourglass markers indicate the distribution of opacities for the entire sample (all model years).
There are 229 1991 and newer observations in the entire 592 observation HHDDV sample.

FIGURE 6-11. OPACITY DISTRIBUTION FOR 1991+ MHDDV



medium-heavy and heavy-heavy duty diesel vehicles tested. The selected model year groupings are designed to reflect periods of fairly similar engine technology. 1980 and earlier engines are presented as a single group and represent relatively unsophisticated, mechanically controlled engines. The 1980 through 1983 engine group reflects those engines certified just prior to the advent of transient emissions certification requirements and the 1984 through 1987 engine group reflects the first generation of engines certified to meet those requirements. The 1988 through 1990 model year grouping recognizes the advent of particulate matter emissions testing requirements and, finally, the 1991 and newer engine grouping reflects the beginning and evolution of the era of stringent NO_x and particulate emissions control.

As illustrated in Figures 6-2 through 6-11, there is a substantial difference between the opacity distributions for older medium-heavy and heavy-heavy duty diesel vehicles. The opacity distributions for older medium-heavy duty diesel vehicles reflect a much greater fraction of vehicles in the low opacity ranges than is the case for heavy-heavy duty diesel vehicles. However, this difference steadily declines with newer model years and is not evidenced at all for the group of 1991 and newer vehicles. It is postulated that this relationship primarily results from the generally lower level of penetration of turbocharger technology in the medium-heavy engine class. Analysis performed in support of the TSD for the original HDVIP revealed that naturally aspirated engines are much less likely to fail the snap-acceleration test, and this is reflected in the lower failure rate for medium-heavy duty diesel vehicles. Table 6-5 presents basic descriptive statistics for the same vehicle groupings which further illustrate this trend. Based on these observations and the fact that the recommended HDVIP cutpoints vary for pre-1991 vehicles and 1991 and newer vehicles, separate failure rate model forms were investigated for the recommended HDVIP

opacity cutpoints. Various linear, second order, and logarithmic constructions were evaluated through least squares regression analysis and the functions presented in Figures 6-12 through 6-14 were selected as the most appropriate descriptive models for the J1667 database.

TABLE 6-5. BASIC OPACITY STATISTICS FOR THE RANDOM TRUCK OPACITY SURVEY DATABASE

Model Year	Heavy-Heavy Duty Diesel Vehicles				Medium-Heavy Duty Diesel Vehicles			
	Vehicles Tested	Median Opacity	Mean Opacity	Standard Deviation	Vehicles Tested	Median Opacity	Mean Opacity	Standard Deviation
Pre-1980	57	65.4	59.6	31.8	29	28.3	42.7	31.6
1980-83	51	31.8	40.7	27.1	50	27.5	35.6	24.1
1984-87	146	27.9	38.2	27.8	116	25.6	31.4	23.7
1988-90	109	22.3	27.1	19.4	81	22.8	25.9	17.4
1991 and Newer	229	6.4	9.8	11.8	134	6.5	9.4	8.7

FIGURE 6-12. FAILURE RATE RELATION FOR PRE-1991 HHDDV

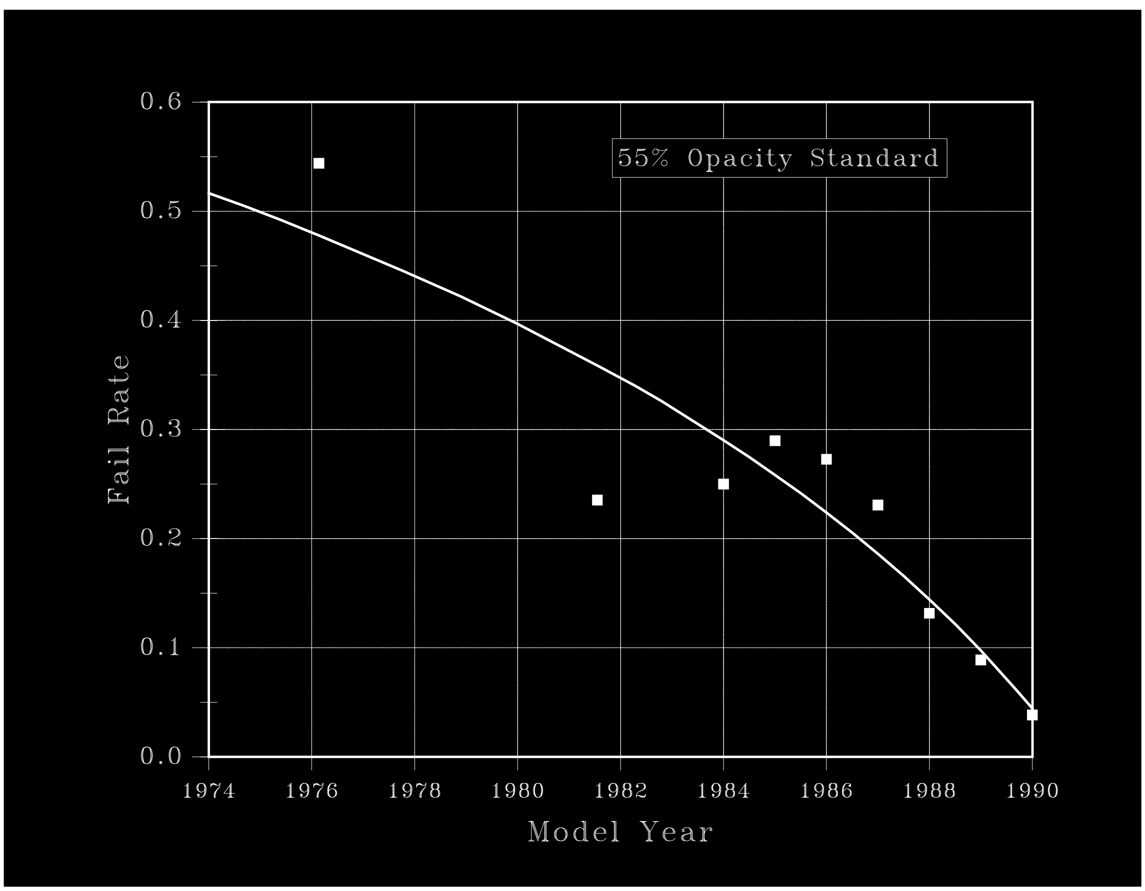


FIGURE 6-13. FAILURE RATE RELATION FOR PRE-1991 MHDDV

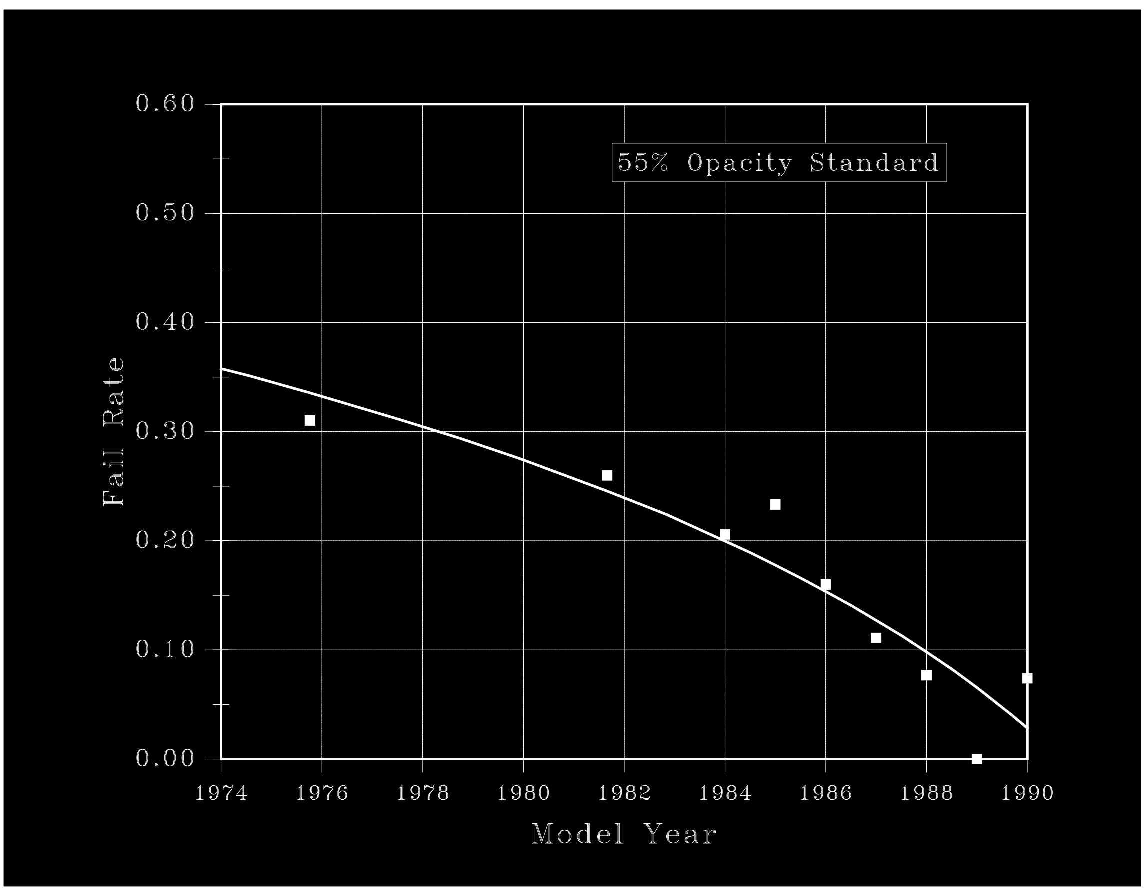
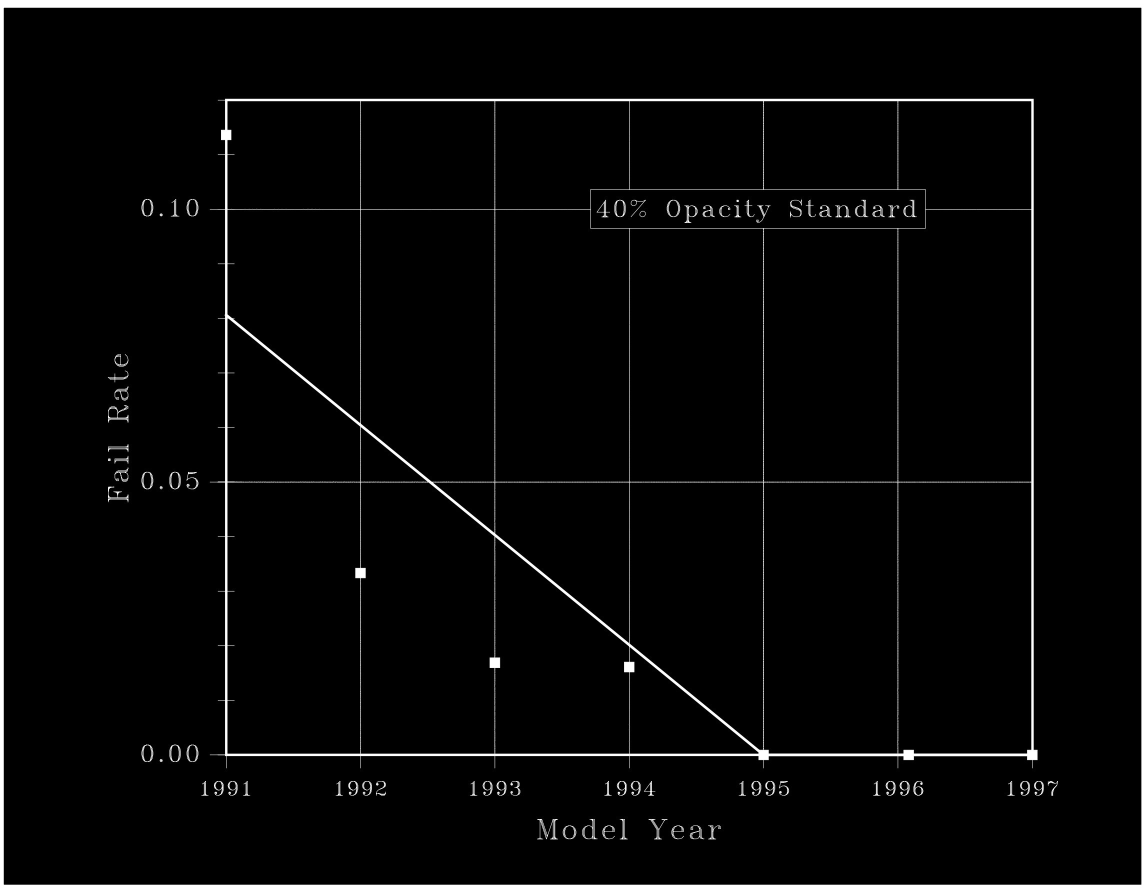


FIGURE 6-14. FAILURE RATE RELATION FOR POST-1990 HHDDV AND MHDDV



For pre-1991 heavy-heavy duty diesel vehicles, the best fit regression model was determined to be:

$$\text{Failure Rate} = -0.727934 + 0.396924\,(\ln \text{Age}) \qquad r^2 = 0.84$$

$$\begin{array}{cc} (0.1579) & (0.0648) \\ (t = -4.6) & (t = 6.1) \end{array}$$

where age is determined as 1997 minus the test engine model year.

For pre-1991 medium-heavy duty diesel vehicles, the best fit regression model was determined to be:

$$\text{Failure Rate} = -0.509942 + 0.276716\,(\ln \text{Age}) \qquad r^2 = 0.87$$

$$\begin{array}{cc} (0.1006) & (0.0413) \\ (t = -5.1) & (t = 6.7) \end{array}$$

The reduced age coefficient for medium-heavy duty diesel vehicles reflects the lower failure rate deterioration for those vehicles (relative to heavy-heavy duty diesel vehicles) and the magnitude of this reduction is easily observed by comparing Figures 6-12 and 6-13. During the 1997 calendar year, the medium-heavy duty model predicts a failure rate of about 3 percent for 1990 engines rising to about 25 percent for 1976 engines, whereas its heavy-heavy counterpart predicts a rise from about 4 percent for 1990 engines to 48 percent for 1976 engines.

The similarity in failure rate behavior for 1991 and newer medium- and heavy-heavy duty diesel vehicles was confirmed when separate models were evaluated for each. As expected, the resulting model coefficients were virtually identical and as a result, a combined medium- and heavy-heavy duty engine model was constructed. Since the observed data (see Figure 6-14) indicated a zero failure rate for engines up to two years of age, a lagged model construction based on engine age minus two was employed. The resulting model developed for all 1991 and newer heavy duty engines was:

$$\text{Age le } 2: \quad \text{Failure Rate} = 0$$

$$\text{Age} > 2: \quad \text{Failure Rate} = \underset{\substack{(0.0045) \\ (t = 4.5)}}{0.020152} \ (\text{Age} - 2) \qquad r^2 = 0.84$$

For all three failure rate models, age was measured relative to 1997 (i.e., a 1991 engine was assumed to be six years old, a 1977 engine 20 years old). It should also be noted that the best fit model for 1991 and newer engines was actually a second order lagged age model, where a correlation coefficient of 0.94 was observed. (Visual examination of Figure 6-14 easily illustrates the superiority of the second order fit.) However, such a model would imply inordinate failure rate increases as engines age beyond 10 years or so. It is believed that as 1991 and newer engines age beyond the six years currently in evidence that the selected linear model will more accurately describe engine performance than the alternative second order model that was rejected.

Using the models presented above, expected failure rates were developed for the 1999 and 2010 HDVIP and PSIP evaluation years. Since criteria pollutant benefits associated with HDVIP and PSIP implementation are determined using the ARB motor vehicle emissions inventory model MVEI7G, failure rates were determined for vehicles up to 35 model years in age. Table 6-6 and Figures 6-15 and 6-16 present the estimated failure rates. The discontinuities observed around the 1990 and 1991 model year vehicle failure rates reflect the interface of the respective proposed 55 and 40 percent opacity cutpoints. Applying these model year-specific failure rates to the heavy duty diesel vehicle distribution forecast by the ARB's MVEI7G emission factor model yields estimated fleet average failure rates of 13.1 percent in 1999 and 9.2 percent in 2010.

TABLE 6-6. FAILURE RATES FOR PROGRAM EVALUATION YEARS

1999 Evaluation Year			2010 Evaluation Year		
Model Year	HHDDV Failure Rate	MHDDV Failure Rate	Model Year	HHDDV Failure Rate	MHDDV Failure Rate
1999	0.0%	0.0%	2010	0.0%	0.0%
1998	0.0%	0.0%	2009	0.0%	0.0%
1997	2.0%	2.0%	2008	2.0%	2.0%
1996	4.0%	4.0%	2007	4.0%	4.0%
1995	6.1%	6.1%	2006	6.1%	6.1%
1994	8.1%	8.1%	2005	8.1%	8.1%
1993	10.1%	10.1%	2004	10.1%	10.1%
1992	12.1%	12.1%	2003	12.1%	12.1%
1991	14.1%	14.1%	2002	14.1%	14.1%
1990	18.6%	12.7%	2001	16.1%	16.1%
1989	22.4%	15.4%	2000	18.1%	18.1%
1988	25.8%	17.8%	1999	20.2%	20.2%
1987	29.0%	20.0%	1998	22.2%	22.2%
1986	32.0%	22.0%	1997	24.2%	24.2%
1985	34.7%	23.9%	1996	26.2%	26.2%
1984	37.3%	25.7%	1995	28.2%	28.2%
1983	39.7%	27.4%	1994	30.2%	30.2%
1982	41.9%	29.0%	1993	32.2%	32.2%
1981	44.1%	30.5%	1992	34.3%	34.3%
1980	46.1%	31.9%	1991	36.3%	36.3%
1979	48.1%	33.3%	1990	48.1%	33.3%
1978	49.9%	34.5%	1989	49.9%	34.5%
1977	51.7%	35.8%	1988	51.7%	35.8%
1976	53.4%	37.0%	1987	53.4%	37.0%
1975	55.0%	38.1%	1986	55.0%	38.1%
1974	56.5%	39.2%	1985	56.5%	39.2%
1973	58.0%	40.2%	1984	58.0%	40.2%
1972	59.5%	41.2%	1983	59.5%	41.2%

1971	**60.9%**	**42.2%**	**1982**	**60.9%**	**42.2%**
1970	**62.2%**	**43.1%**	**1981**	**62.2%**	**43.1%**
1969	**63.5%**	**44.0%**	**1980**	**63.5%**	**44.0%**
1968	**64.8%**	**44.9%**	**1979**	**64.8%**	**44.9%**
1967	**66.0%**	**45.8%**	**1978**	**66.0%**	**45.8%**
1966	**67.2%**	**46.6%**	**1977**	**67.2%**	**46.6%**
1965	**68.3%**	**47.4%**	**1976**	**68.3%**	**47.4%**

FIGURE 6-15. PREDICTED FAILURE RATES FOR 1999 EVALUATION YEAR

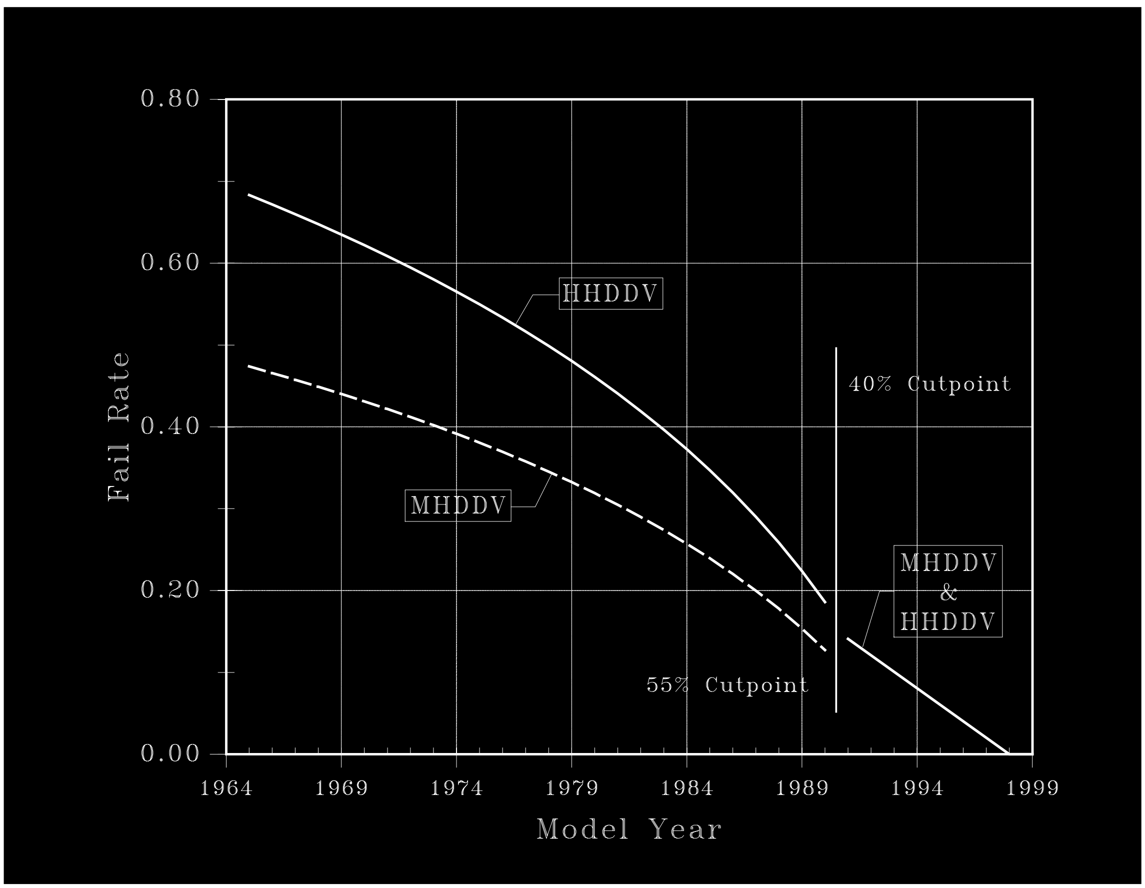
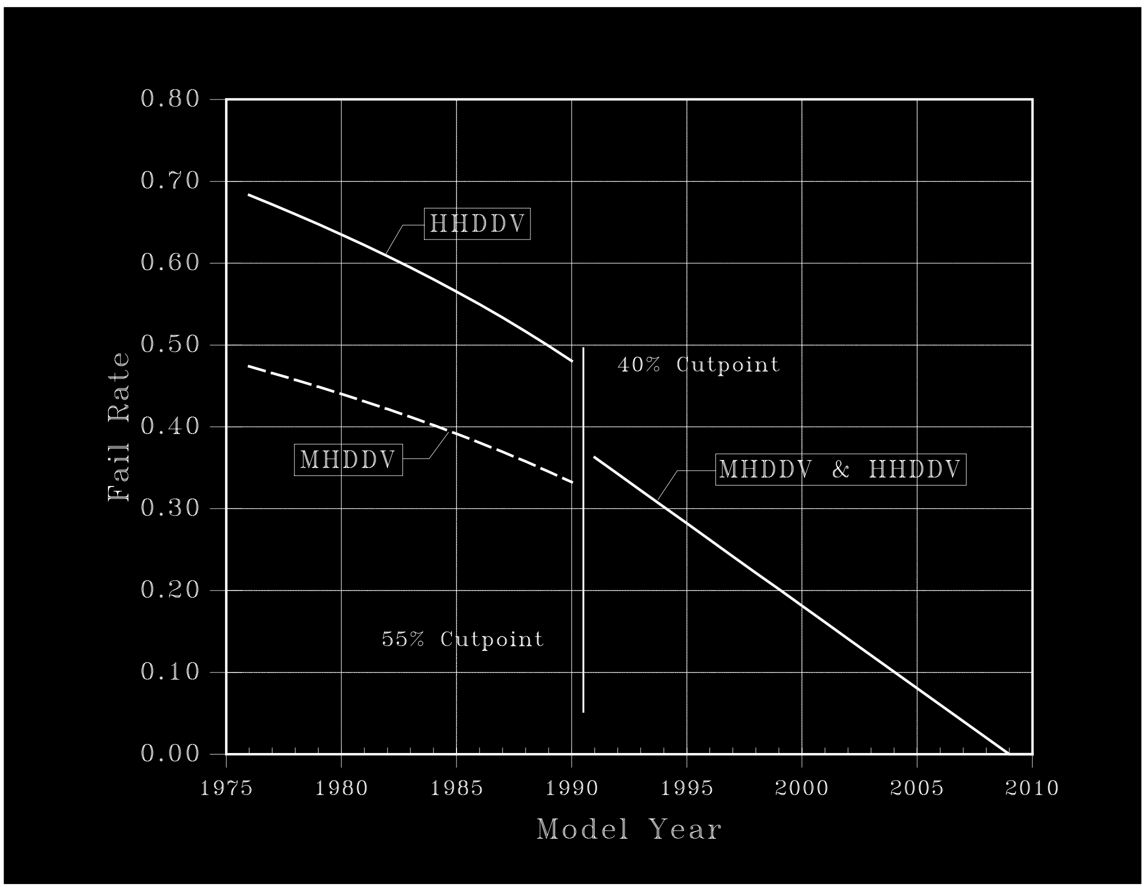


FIGURE 6-16. PREDICTED FAILURE RATES FOR 2010 EVALUATION YEAR



Note that the tabulated failure rates do not account for the improvement in vehicle maintenance that is expected to accrue following HDVIP and PSIP implementation. This is consistent with the use of MVEI7G to determine program emission reduction benefits. Since MVEI7G estimates all smoke enforcement program impacts on the basis of an adjustment to a baseline (i.e., no HDVIP and PSIP) emission rate regardless of the evaluation year, it is critical that MVEI7G inputs reflect the aggregate impacts of the HDVIP and PSIP in any given year. Therefore, while the actual HDVIP and PSIP failure rate in 2010 will be less than that indicated in Table 6-6 due to improved vehicle maintenance (lower by about 7 percent as described in Sections 6.5.1 and 6.5.2 below), the overall impact of the HDVIP and PSIP (in terms of improved maintenance plus failure-driven repairs) will be equivalent to the baseline failure rates presented in Table 6-6.

6.5 PROGRAM COSTS TO VEHICLE OWNERS

Both the HDVIP and PSIP will impose costs on the regulated community beyond the administrative costs estimated in Section 6.3. Vehicle owners will be required to repair failed vehicles and clear the associated smoke citations issued by the ARB. Implementation of the HDVIP and PSIP will also induce a fraction of vehicle owners to expend funds on additional vehicle maintenance to avoid potential citation costs. Based on the failure rate expectations presented in Section 6.4 and experience gleaned from the original HDVIP program administered from the end of 1991 to the end of 1993, estimates can be derived for these vehicle owner costs.

6.5.1 Costs of Failed Vehicle Repair

The total costs of vehicle repair depend on two factors: (1) the number of malmaintained vehicles identified by the HDVIP and PSIP and subsequently repaired, and (2) the fraction of vehicles voluntarily repaired in response to HDVIP and PSIP implementation (i.e., the deterrence effect of the programs). The number of malmaintained vehicles identified by the HDVIP and PSIP is dependent on the fraction of vehicles inspected, the fraction of inspected vehicles failed, the fraction of those failures that are repaired, and the average vehicle repair cost.

The fraction of vehicles inspected is a function of the number of inspections that are performed under the HDVIP and the PSIP, minus the fraction of vehicles inspected under both programs. The ARB estimates that approximately 40,000 HDVIP inspections will be performed annually. As indicated in Section 6.3, an estimated 291,387 inspections will be performed in 1999 and an estimated 396,939 inspections will be performed in 2010 under the PSIP. The ARB MVEI7G emissions inventory model indicates that 570,561 heavy duty diesel vehicles will be in operation in California in 1999 and 777,214 heavy duty diesel vehicles will be in operation in 2010. Given these estimates, there is a 7.0 percent probability of any one vehicle being inspected under the HDVIP program in 1999 and a 5.1 percent probability in 2010 (the probability declines over time since ARB staffing does not change while the total vehicle population increases). Assuming that fleet and non-fleet vehicles have an equal probability of inspection, approximately 20,429 fleet vehicles will be inspected under both the HDVIP and PSIP in 1999 and 2010. (This dual inspection of fleet vehicles can serve as an effective PSIP compliance check upon implementation of a proper fleet vehicle tracking system.) Therefore, the number of individual vehicles inspected net of HDVIP and PSIP overlap is estimated to be 310,968 (40,000+291,397-20,429) in 1999 and

416,510 (40,000+396,939-20,429) in 2010, indicating a net inspection rate of 54.5 percent of heavy duty diesel vehicles in 1999 and 53.6 percent of heavy duty diesel vehicles in 2010.

The overall MVEI7G heavy duty diesel vehicle populations can be distributed across component vehicle types (light-heavy, medium-heavy, heavy-heavy, and urban transit bus) using MVEI7G vehicle type and model year distribution functions. Applying the vehicle inspection rate as determined above and the model year-specific expected failure rates presented in Table 6-6 to the model year and vehicle class-specific populations yields estimated program failure populations. For light-heavy duty diesel vehicles (LHDDV), which were not included in the Random Truck Opacity Survey used to derive expected HDVIP and PSIP failure rates, the expected failure rate is taken as one-third that of medium-heavy duty diesel vehicles based on default MVEI7G smoke program relationships. This calculation yields estimated fleet average failure rates of 13.1 percent in 1999 and 9.2 percent in 2010.

The estimated failures rates are assumed to apply equally to both the HDVIP and PSIP. While there are intuitive reasons to think that (in the aggregate) fleet vehicles might perform differently than non-fleet vehicles due to such issues as more frequent maintenance, it must be recognized that the Random Truck Opacity Survey was based on the random selection of heavy duty diesel vehicles for smoke measurement and includes both fleet and non-fleet vehicles, presumably in proportion to the respective populations of each on California roadways. Therefore, statistics derived through analysis of the Random Truck Opacity Survey database reflect the aggregate behavior of fleet and non-fleet vehicles and can be applied to overall California heavy duty diesel populations without quantification of fleet/non-fleet differentials.

For 1999, the failure rate calculation requires no further adjustment since the current absence of active smoke program enforcement will not induce additional deterrence-driven heavy duty diesel vehicle repair. However, for 2010 an adjustment is required to account for the fact that implementation of the proposed HDVIP and PSIP will influence the failure rate of heavy duty diesel vehicles between 1999 and 2010 through the renewal of deterrence-driven vehicle repair. An estimate of the size of the necessary adjustment for 2010 can be derived using data from the original HDVIP program.

Between 1991 and 1993, the failure rate under the original HDVIP declined from 44.7 percent to 18.5 percent as a result of improved vehicle maintenance. While it is possible that this failure rate would have continued to decline before stabilizing (at a level where deteriorating vehicles just offset the annual effects of improved maintenance), there is reason to believe that any continued decline would have been modest. The TSD for the original HDVIP (Section 7.3.2) estimated that stabilization would not occur until the fifth year of the program, but even so, the expected failure rate after two program years had declined by 88 percent of the total five year expected decline. Moreover, the observed failure rate of the first year of the original HDVIP was virtually identical to that estimated in the TSD (44.7 percent versus 44.0 percent) while the observed failure rate entering the third year of the original HDVIP program (18.5 percent) was already less than the TSD's expected fifth year stabilization rate (21.2 percent). It, therefore, seems reasonable to view the stabilization period as significantly shorter than estimated in the TSD for the original HDVIP and that the beginning year and ending year observations of the original HDVIP serve as a good estimate of the magnitude of the stabilization effect.

The failure rates for 1999, derived in Section 6.4.3, combined with vehicle distribution data from the ARB's MVEI7G emission factor model yield estimated fleet-average failure rates of 13.1 percent for all heavy duty diesel vehicles and 20.0 percent for the pre-1993 model year segment which would have been covered by the original HDVIP at the time of its suspension. While the test procedures for the proposed and original HDVIP are different (SAE J1667 versus SAE J1243), the overall stringency of the two programs is equivalent and each would be expected to detect the same population of excess opacity vehicles. (In fact, the SAE J1667 procedure measures smoke at an average of 5 opacity points or so less than the SAE J1243 procedure, but this decrease in "stringency" is offset by an equal increase in pre-1993 heavy duty diesel vehicle smoke levels due to fleet aging.)

The estimated 20.0 percent failure rate for pre-1993 heavy duty diesel vehicles implies that only limited backsliding of maintenance practices has occurred since the suspension of the original HDVIP at the end of 1993 (when the observed failure rate for pre-1993 vehicles was 18.5 percent). While a substantial maintenance improvement due to implementation of the original HDVIP is still evident (since the observed failure rate during the first year of the original HDVIP was 44.7 percent), further eroding of this improvement can be expected in the absence of implementation of the proposed HDVIP and PSIP. Based on the 18.5 percent failure rate at the end of the original HDVIP and the 20.0 percent failure rate for an equivalent vehicle population in the Random Truck Opacity Survey, it is reasonable to expect a 7 percent decline in future year failure rates under the proposed HDVIP program (relative to the failure rates forecast using the Random Truck Opacity Survey database). Applying this factor to the estimated 2010 failure populations presented in Table 6-6 provides an estimate of the stabilized failure populations which can be expected to be observed in that year. This adjustment reduces the expected HDVIP and PSIP failure rate in 2010 from 9.2 percent to 8.6 percent.

Observations from the original HDVIP also provide a good indication of the fraction of failed vehicles that will be repaired under the proposed HDVIP and PSIP. Under the original program, 8,493 repair citations were issued. Of these, 392 are still pending yielding a net of 8,101 citations which are not currently under review. 6,356 of these citations have been cleared implying a 78.5 percent repair rate for vehicles cited. This again agrees remarkably well with the 79.1 percent overall repair rate estimated in the TSD (Section 7.2.3) for the original HDVIP. As a result, the 78.5 percent observed repair rate from the original HDVIP is taken to be a valid estimate of the expected repair rate under the proposed HDVIP and PSIP.

Combining these factors yields an estimate of 31,859 repaired heavy duty diesel vehicles in 1999 and 27,941 repaired heavy duty diesel vehicles in 2010. Chapter 5 presents the estimated average costs of model year-specific repairs necessary to bring vehicles into compliance with proposed HDVIP and PSIP standards. When these costs are weighted in accordance with expected failure populations, the aggregate per-vehicle repair cost of repair is estimated to be $664 in 1999 and $581 in 2010. Therefore, the overall cost of vehicle repair is estimated to be $21.16 million in 1999 and $16.23 million in 2010. Table 6-7 presents a summary of the derivation of these estimates.

TABLE 6-7. ESTIMATED FAILED VEHICLE REPAIR COSTS[1]

	1999	2010
Vehicles Subject to HDVIP and PSIP	570,561	777,214
Aggregate HDVIP and PSIP Inspection Rate	0.5450	0.5359
Aggregate HDVIP and PSIP Failure Rate	0.1306	0.0855
HDVIP and PSIP Repair Rate	0.7846	0.7846
Failures Repaired Under the HDVIP and PSIP	31,859	27,941
Average Cost of Repair	$664	$581
Total Failed Vehicle Repair Cost	$21,162,379	$16,229,616

[1]Totals do not exactly match component calculations due to rounding.

6.5.2 Costs of Improved Vehicle Maintenance

A substantial number of vehicles will be voluntarily repaired in response to HDVIP and PSIP implementation due to the threat of inspection and citation issuance. Historically, significant reductions in excess emissions have been observed due to this deterrence effect upon implementation of similar programs (e.g., vehicle inspection programs for light duty vehicles). The TSD for the original HDVIP (Section 7.2.3) asserted that this same phenomena was likely to be observed upon implementation of the original HDVIP. Data collected during the two year operational period of that program confirm this assertion.

In the first two years of the original HDVIP, the observed failure rate declined by nearly 58 percent, validating the expectation of a substantial deterrence effect (since less than 10 percent of the heavy duty diesel vehicles in operation in California had actually been inspected under the original HDVIP). This reduction in combination with the total number of vehicles inspected in the original HDVIP implies that approximately 26 percent of heavy duty diesel vehicles were subjected to successful deterrence-driven repairs due to original HDVIP implementation. Data from the recent Random Truck Opacity Survey suggests that this deterrence effect has backslid by about 8 percent since the suspension of the original HDVIP program at the end of 1993 (see Section 6.5.1 above), but a significant effect is still evident. Based on the observed Random Truck Opacity Survey results and data from the original HDVIP it appears that over 24 percent of heavy duty diesel vehicles will be subjected to deterrence-based repairs during the first year of proposed HDVIP and PSIP implementation and further, that this deterrence effect will rise to approximately 26 percent in subsequent program years (as the losses due to backsliding since 1993 are reclaimed).

Estimating the cost of this deterrence effect is problematic. First, some of the benefit is derived from avoided tampering, an occurrence which results in no net cost to vehicle owners. Second, it is very likely that those vehicles with minor problems will be preferentially maintained since it is this population for which the threat of a $300 citation penalty poses the greatest risk (for vehicles requiring greater repairs, the risk-adjusted value of receiving a citation could be more cost-effective than the actual repairs). Finally, the issue of repair lifetime must be considered. Certainly 26 percent of malmaintained vehicles are not repaired annually (although there is an initial "spike" in repairs during the initial years of smoke program enforcement; this "spike" has already occurred in California due to the original HDVIP). This instead represents the cumulative fraction of vehicles repaired before a steady-state condition is achieved wherein the annual deterrence-driven repair impact of vehicles is just offset by an equal (but opposite) emissions increase from deteriorating vehicles.

For this analysis, it was assumed that all deterrence effects are achieved through actual vehicle repair (i.e., <u>no</u> vehicle owners are assumed to simply avoid tampering or to restore previously tampered items at no cost), and that the average cost of deterrence-driven repairs is equal to the average cost of failure-based repairs (i.e., deterrence-driven repairs are <u>not</u> assumed to be cheaper on average than failure-driven repairs). These assumptions should maximize the cost of deterrence-based vehicle repair and, therefore, yield a conservative estimate of HDVIP- and PSIP-driven impacts. The stabilized annual fraction of vehicle owners performing deterrence-based repairs is equal to the differential between the estimated future failure rates with and without the deterrence effect considered.

Based on these assumptions, a total of 3,413 heavy duty diesel vehicles in 1999 and 5,074 heavy duty diesel vehicles in 2010 are expected to perform deterrence-driven repair in direct response to implementation of the proposed HDVIP and PSIP. Combining these estimates with the average per-vehicle estimated repair costs of $664 in 1999 and $581 in 2010 yields estimates for the deterrence-based cost of vehicle repair of $2.27 million in 1999 and $2.95 million in 2010.

6.5.3 Cost of Failure Citation Penalties

Vehicle owners failing HDVIP inspections are subject to penalties ranging from $300 to $1,800 depending on the timing and effectiveness of vehicle repairs. Once again, data from the original HDVIP suspended at the end of 1993 provides a good basis on which to access the magnitude of citation costs expected under the proposed HDVIP. Under the original HDVIP, 6,356 citations were cleared at a total cost of $2,075,000. This implies an average citation cost of $326. Since the penalty structure of the proposed HDVIP is identical to that of the original HDVIP, this $326 average citation cost can be applied to the estimated 5,223 vehicles expected to be failed in 1999 and the 3,420 expected failures in 2010 to derive total expected citation penalty costs in both years. The resulting estimates are $1.34 million in 1999 and $0.88 million in 2010. (Only HDVIP-driven heavy duty diesel vehicle failures are considered to incur citation penalties. PSIP-driven failures are assumed to be detected and corrected by the affected fleet owner, exclusive of the citation process.)

6.5.4 Indirect Program Costs

In addition to the vehicle repair and citation penalty costs described above, vehicle owners will also be subjected to a lost opportunity cost equal to the value of vehicle and driver out-of-service time. For the PSIP, it is assumed that both inspections and any necessary repairs will be accomplished during the normal out-of-service period for subject vehicles.

As a result, no opportunity costs are incurred under the PSIP. For the proposed HDVIP, the same assumptions used in the TSD for the original HDVIP (Section 7.2.3) are used to estimate costs as follows:

- **Weighted average repair time is 1.03 days,**
- **The average out-of-service time for a failed inspection is 15 minutes,**
- **The average out-of-service time for a passed inspection is 3 minutes, and**
- **The average driver out-of-service time for a repair is 2 hours.**

For the proposed HDVIP opportunity cost estimate, the weighted average daily capital charge for heavy duty diesel vehicles has been increased from the $70 per day value used for the original HDVIP TSD to $100 per day. Similarly, the fully burdened labor rate for heavy duty diesel vehicle drivers has been increased from $19 per hour to $25 per hour. Combining these assumption with the vehicle inspection, failure, and repair estimates presented in the preceding subsections yields an estimated lost driver time opportunity cost of $0.30 million in 1999 and $0.22 million in 2010 and an estimated lost vehicle time opportunity cost of $0,48 million in 1999 and $0.34 million in 2010. The total lost opportunity cost is estimated to be $0.77 million in 1999 and $0.57 million in 2010.

6.5.5 Cost of Reduced Fuel Consumption

Repairs undertaken to reduce heavy duty diesel vehicle smoke (either through failure of the HDVIP or PSIP or through the deterrence effects of the programs) will impact heavy duty diesel vehicle fuel consumption in California. This impact accrues as a direct cost to heavy duty diesel vehicle owners and must be accounted for in determining overall program costs.

Section 7.4 presents an estimate of the magnitude of this fuel consumption impact. Based on the same malperformance model used to estimate criteria pollutant impacts, a 0.69

percent decrease in heavy duty diesel vehicle fuel consumption is estimated in 1999 and a 0.66 percent decrease in heavy duty diesel vehicle fuel consumption is estimated in 2010 due to HDVIP and PSIP implementation. Using the fuel consumption estimates forecast by the MVEI7G model for those years, these percentages translate into a net diesel fuel savings of 16.74 million gallons in 1999 and 19.22 million gallons in 2010. Assuming a $1.30 per gallon cost of diesel fuel yields estimates of a net savings of $21.76 million in 1999 and $24.98 million in 2010 due to repair-driven decreases in heavy duty diesel vehicle fuel consumption.

6.6 TOTAL PROGRAM COSTS

Section 6.3 presents estimates of total HDVIP and PSIP staffing and administration costs in both 1999 (the first full year of program implementation) and 2010. Section 6.5 presents costs incurred by the regulated industry due to vehicle inspection, repair, smoke citation penalties, and reduced fuel consumption. Table 6-8 summarizes these estimated HDVIP and PSIP costs. As indicated, the annual net cost to California (exclusive of transfer payments) is estimated to be $22.37 million in 1999, dropping to $20.20 million in 2010. Total program costs are adjusted to exclude the cost of citation penalties since this cost represents a transfer

TABLE 6-8. SUMMARY OF HDVIP AND PSIP COSTS

	1999	2010
Administrative Costs to the ARB		
Annual Staffing Cost (HDVIP)	$2,826,928	$2,826,928
Annual Capital Cost (HDVIP)	$48,500	$48,500
Annual Staffing Cost (PSIP)[1]	$0.00	$0.00
Annual Capital Cost (PSIP)[1]	$0.00	$0.00
Annual Contractual Cost for CHP Support	$75,000	$75,000
Total ARB Annual Administrative Cost	$2,950,428	$2,950,428
Administrative Cost to Fleets		
Annual Labor Cost (PSIP)	$1,255,761	$1,642,385
Annual Capital Cost for Smokemeters (PSIP)	$5,005,009	$6,817,787
Annual Cost of Contractual PSIP Inspections (PSIP)	$10,725,351	$14,027,474
Total Fleet Annual Administrative Cost	$16,986,121	$22,487,646
Costs to Vehicle Owners		
Annual Repair Cost (HDVIP + PSIP)	$21,162,379	$16,229,616
Annual Citation Penalty Cost (HDVIP)	$1,337,857	$876,006
Annual Increased Maintenance Cost (HDVIP + PSIP)	$2,267,097	$2,947,141
Annual Lost Opportunity Cost of Time (HDVIP)	$771,936	$567,603
Annual Cost of Fuel (HDVIP + PSIP)	($21,764,145)	($24,983,116)
Total Cost to Vehicle Owners	$3,775,124	($4,362,750)
Net Cost to Vehicle Owners (Excluding Transfer Payments)[2]	$2,437,267	($5,238,756)
Total HDVIP and PSIP Cost		

Unadjusted Total Program Cost	**$23,711,673**	**$21,075,324**
Net Program Cost (Excluding Transfer Payments)[2]	**$22,373,816**	**$20,199,318**

[1] **No additional costs are assumed to accrue to the ARB due to PSIP implementation as all ARB PSIP duties will be fulfilled using HDVIP staff and equipment.**

[2] **Net costs exclude citation penalty costs since these costs represent transfer payments rather than a consumption of resources. The citation penalty cost is accrued by vehicle owners, but net costs to the ARB are reduced by the same amount due to the collection of these penalties.**

payment rather than a payment for consumed resources. The amount of this transfer payment is presented in Table 6-8 as a vehicle owner cost, but in reality the costs allocated to the ARB in Table 6-8 would be reduced by an amount equal to the citation penalty collected. Since this savings to the ARB is not indicated in Table 6-8, the net cost of the program is reduced by the value of this transfer payment.